Ensuring the integrity of research in the Age of open access. A proposal : hashing + public-key cryptography signing.

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Abstract

On ensuring the integrity of research documents in the digital age, a concern of prime importance to the development of open access. New and old solutions are presented, and a utility tool (`tenaciouscookie`).

Introduction

In this report, we propose that where research goes, a way to ensure their integrity is given by the formula : hashing + public-key cryptography signing.

We look at the “old way” of how this would be done, and detail the steps.

We look at a new way of doing this with a utility called `tenaciouscookie` – named so in homage to Aaron Swartz who worked in all of these areas.

In general, such utilities ought to be developed to make the life of researchers easier. And, their development expended to and included in the Web, in various forms (e.g. open access platforms, open access journals, etc., submissions (forms)).

1 Hashing, Public-key signing. The “old way”

We go through the steps of hashing and public-key cryptography signing by using a real example.

1.1 Hash functions

Given a document `document.pdf` (or any other document) produced by a researcher : we detail the steps of hashing followed by public-key signing, the method we propose ought to be used by researchers to digitally ensure the integrity of their research (and towards their readers).

To facilitate narration, discussion and reasoning, we choose a real document produced by a researcher¹.

¹Yitang Zhang. “On the Landau-Siegel Zeros Conjecture”. <https://arxiv.org/abs/0705.4306>. Submitted on 29 May 2007.

On the Landau-Siegel Zeros Conjecture

Yitang Zhang

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1. Introduction

The main result of this paper is the following

Theorem 1 *For any real primitive character χ of modulus D we have*

$$L(1, \chi) > c_1(\log D)^{-17}(\log \log D)^{-1} \quad (1.1)$$

where $c_1 > 0$ is an effectively computable constant.

As a direct consequence of Theorem 1, we have

Theorem 2 *Let $\chi \pmod{D}$ be as in Theorem 1. Then we have*

$$L(\sigma, \chi) \neq 0 \quad (1.2)$$

This hypothetical researcher would proceed to produce what is called a “hash” (a digital signature) for (their) this file.

Hash functions, including SHA-1, are described in Chap. 11. For now it is sufficient to know that SHA-1 compresses x and computes a 160-bit fingerprint. This fingerprint can be thought of as a representative of x .²

When we talk of hashing, hashes, or hash values (more) precisely, we use terminology that is important to keep in mind : additional terms such as “digest” are often found in discussions relating to their uses, and it is good to have a correct idea of their precise meanings.

Hash functions are an important cryptographic primitive and are widely used in protocols. They compute a digest of a message which is a short, fixed-length bit- string. For a particular message, the message digest, or hash value, can be seen as the fingerprint of a message, i.e., a unique representation of a message.³

There are thus the *message* – that which must be encoded – and the *message digest* – the resulting hash value.

We demonstrate this on the basis of a primitive example.

Apply the hash function, SHA-1, to the message "hello";
And, give back the message digest.

```
aaf4c61ddcc5e8a2dabede0f3b482cd9aea9434d
```

And, in real software (here using the Python Standard Library built-in `hashlib` module of various hash functions),

```
>>> hashlib.sha1(b"hello").hexdigest()  
'6f9b9af3cd6e8b8a73c2cdced37fe9f59226e27d '
```

Or,

²Paar and Pelzl 2009. Chapter 10, 10.4.

³Ibid. Chapter 11.

```
>>> message = "hello"
>>> hashlib.sha1(message).hexdigest()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: Unicode-objects must be encoded before hashing
>>> message = "hello".encode('utf-8')
>>> hashlib.sha1(message).hexdigest()
'aaf4c61ddcc5e8a2dabede0f3b482cd9aea9434d '
>>> message
b'hello '
```

On Linux systems this is done with the series of `sha<variant>sum` utilities e.g. `sha256sum` or `sha512sum`, as demonstrated below :

```
$ sha256sum zhang2007landausiegl.pdf
925
  ↪ c988b4a4e2036146aab0021fd78e15c215de954170ce3acbf8430e9181eb
  ↪ zhang2007landausiegl.pdf
```

This hash is unique to this file – “almost”. Almost, probably : maybe.⁴

Theoretically, since the domain of SHA-256 contains $2^{2^{64}-1}$ different messages and the value set only contains 2^{256} different message digests, there must exist at least one possible output that has more than one possible pre-image.

Another important point is that SHA-256 is a deterministic function. This means that if you hash the same message twice, you will get the same digest both times. Hence, “almost unique” should be understood as meaning that SHA-256 will likely produce a different hash for each different input message. This might be false in an abstract mathematical sense, but it is probably true in a more practical sense:

In practice, uniqueness is not determined by the abstract theoretical non-existence of collisions, but by the practical non-existence of collisions. In order to find a collision in SHA-256, you would

⁴The issue is that of collision : when two different messages (can be made to) produce the same hash. Such collisions are evoked, including actual attacks of older versions of SHA, in Paar and Pelzl 2009.

probably have to execute the algorithm some 2^{128} times. It is unlikely that this will happen anytime soon, even if you count the total number of times SHA-256 will ever be executed by anyone in the entire universe combined.

Does a message “exist” if it belongs to a well defined abstract set, or does it “exist” because it has actually been produced and has been represented by someone or something in the physical reality?⁵

The precise uniqueness of this digital signature is related to the two formula given below :

$$\begin{aligned} &2^{2^{64}-1} \\ &= 2^{2^{63}} \\ &= 10^{10^{18.4434..}} \\ &= 1 \cdot 10^{184.434..} \end{aligned}$$

Which describes the domain, or set, of possible different messages. (That can be passed to the SHA-256 algorithm/function, or any such algorithm/function.) We understand this to be an (almost) infinite amount, and understand henceforth $2^{2^{64}-1}$ to be some approximation of (almost-)infinity.

$$\begin{aligned} &2^{256} \\ &= 1.1579.. \cdot 10^{77} \end{aligned}$$

Which describes the domain, or set, of possible different values (“signatures”) that can be generated by (with) the SHA-256 algorithm. This is a finite set, we understand.

1.2 Public-private key signing

A researcher would then go on to create a pair of public-private keys.

This is done according to the GNU Privacy Guard (GnuPG, or `gpg`) “The GNU Privacy Handbook” like so :

⁵Hellström 2015.

```
alice% gpg --gen-key
```

With the following output, when done in actuality :

```
$ gpg --gen-key
gpg (GnuPG) 2.2.4; Copyright (C) 2017 Free Software
  ↳ Foundation, Inc.
This is free software: you are free to change and
  ↳ redistribute it.
There is NO WARRANTY, to the extent permitted by law.

Note: Use "gpg --full-generate-key" for a full featured key
generation dialog.

GnuPG needs to construct a user ID to identify your key.

Real name: researcher
Email address: email
Not a valid email address
Email address: email@address
You selected this USER-ID:
  "researcher <email@address>"

Change (N)ame, (E)mail, or (O)kay/(Q)uit? 0
We need to generate a lot of random bytes. It is a good idea
to perform some other action (type on the keyboard, move the
mouse, utilize the disks) during the prime generation; this
gives the random number generator a better chance to gain
enough entropy.
...
gpg: key DB167D229155B65B marked as ultimately trusted
gpg: revocation certificate stored as '/home/.../.gnupg/
  ↳ openpgp-revocs.d/
  ↳ B5A4BB445AF838CA9B42BC72DB167D229155B65B.rev'
public and secret key created and signed.

pub   rsa3072 ... [SC] [expires: ...]
       B5A4BB445AF838CA9B42BC72DB167D229155B65B
uid           researcher <email@address>
sub   rsa3072 ... [E] [expires: ...]
```

Whereas the alternative command appearing as a note gives the following

```
$ gpg --full-generate-key
...
```

```
Please select what kind of key you want:
  (1) RSA and RSA (default)
  (2) DSA and Elgamal
  (3) DSA (sign only)
  (4) RSA (sign only)
Your selection?
```

A user (researcher) may then check for (the existence of) their key :

```
$ gpg --list-keys
/home/.../.gnupg/pubring.kbx
-----
pub   rsa3072 ... [SC] [expires: ...]
      B5A4BB445AF838CA9B42BC72DB167D229155B65B
uid           [ultimate] researcher <email@address>
sub   rsa3072 ... [E] [expires: ...]
```

By which command, `gpg --list-keys`, only the public key will be listed.
And, for their private (“secret”) key :

```
$ gpg --list-secret-keys
/home/.../.gnupg/pubring.kbx
-----
sec   rsa3072 ... [SC] [expires: ...]
      B5A4BB445AF838CA9B42BC72DB167D229155B65B
uid           [ultimate] researcher <email@address>
ssb   rsa3072 ... [E] [expires: ...]
```

And, for both key’s ID’s⁶ :

```
$ gpg --list-secret-keys --keyid-format LONG
gpg: checking the trustdb
gpg: marginals needed: 3  completes needed: 1  trust model:
    => pgp
gpg: depth: 0  valid: 2  signed: 0  trust: 0-, 0q, 0n, 0m
    => , 0f, 2u
gpg: next trustdb check due at ...
```

⁶`gpg --list-keys` nor `gpg --list-secret-keys` alone will not give the keys’ id.


```

/home/.../.gnupg/pubring.kbx
-----
sec    rsa3072/DB167D229155B65B ... [SC] [expires: ...]
        B5A4BB445AF838CA9B42BC72DB167D229155B65B
uid                [ultimate] researcher <email@address>
ssb    rsa3072/CB4D605828B18EDA ... [E] [expires: ...]

```

Where DB167D229155B65B describes the public key, and CB4D605828B18EDA the private key.

The key ID's are important for operations such as deletion of keys.

```

$ gpg --delete-key DB167D229155B65B
...

gpg: there is a secret key for public key "DB167D229155B65B"!
gpg: use option "--delete-secret-keys" to delete it first.

```

(Finally,) Signing of a file is done like so :

The command-line option `-sign` is used to make a digital signature. The document to sign is input, and the signed document is output.

```

alice% gpg --output doc.sig --sign doc
7

```

And, thus :

```

$ gpg --output zhang2007landausiegl.pdf.sig --sign
  ↪ zhang2007landausiegl.pdf

```

The output is a document `zhang2007landausiegl.pdf.sig` of type “detached OpenPGP signature”.

```

$ gpg --verify zhang2007landausiegl.pdf.sig
gpg: Signature made ...
gpg:                using RSA key
  ↪ B5A4BB445AF838CA9B42BC72DB167D229155B65B
gpg: Good signature from "researcher <email@address>" [
  ↪ ultimate]

```

⁷The GNU Privacy Handbook.

We suggest the researcher uploads this – now encrypted and signed – file to any platform – it should not matter, along with the unencrypted, unsigned file for convenience. For convenience, one version is uploaded encrypted, one version is uploaded in the clear. But, should still be checked every time / in any case.

Given a signed document, you can either check the signature or check the signature and recover the original document. To check the signature use the `-verify` option. To verify the signature and extract the document use the `-decrypt` option. The signed document to verify and recover is input and the recovered document is output.

```
blake% gpg --output doc --decrypt doc.sig
```

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The signing of the original document itself through public-private key cryptography should be enough, but the hash value may be certified in the same way as well.

```
$ sha512sum zhang2007landausiegl.pdf >  
  ↪ zhang2007landausiegl_pdf_hash_.txt  
$  
$ gpg --output hash.sig --sign zhang2007landausiegl_pdf_hash_  
  ↪ .txt  
$
```

2 tenaciouscookie : a utility to certify the authenticity of digitally published research.

2.1 sha3-tc.py : SHA3 class hash functions utility program.

A utility called `sha3-tc.py` is first presented that uses the latest class of SHA3 hashing algorithms (instead of SHA2 class algorithms like SHA-256 or SHA-512) :

⁸Ibid.

```
$ python3 sha3-tc.py zhang2007landausiegl.pdf
a36aabf486471783448f04b1b3b4d2eeecfca5c5363b4169570398dbf35725fdf3247f38da2
↪
ec4af8a13f38b558d073cfc94a1e3ed07ab5551b97821ed77e043
```

Here, specifically the `sha3_512` implementation of the Python Standard Library is used (the highest available to our knowledge within that same library).

It belongs to the implementations officially recognized by the SHA3 working group.⁹

A `sha3sum` utility, of the likes of the `sha<variant>sum` utilities, does not currently exist for Linux.

2.2 tenaciouscookie : easy signature creation.

```
$ python3 tc3.py zhang2007landausiegl.pdf
zhang2007landausiegl.pdf.sig signature file created for
↪ zhang2007landausiegl.pdf
```

In the future, we would like to implement this as a (native) command-line utility, that may be called like so :

```
$ tenaciouscookie filename.pdf
filename.pdf.sig signature file created for filename.pdf
```

But, for now, this is enough. Others may improve on it.

Future implementations may do hashing and signing together (in what order, or how exactly, remains an open question).

Note that this utility currently requires version 3.6 or higher of Python (3)¹⁰.

⁹“Implementations”. <https://keccak.team/software.html>

¹⁰“New in version 3.6: SHA3 (Keccak) and SHAKE constructors `sha3_224()`, `sha3_256()`, `sha3_384()`, `sha3_512()`, `shake_128()`, `shake_256()`.”. <https://docs.python.org/3/library/hashlib.html>

```

1  import sys
2  import shlex
3  from subprocess import Popen, PIPE
4
5
6
7
8  if len(sys.argv) == 2:
9      filename = sys.argv[1]
10 else:
11     print('Error : you provided ' + str(len(sys.argv)) + '
        ↳ argument(s).')
12     print('Usage : provide a file name as additional argument to
        ↳ the script (2 in total).')
13
14
15 cmd = 'gpg --output {}.sig --sign {}'.format(filename,
        ↳ filename)
16
17
18 Popen(shlex.split(cmd), stdout=PIPE, stdin=PIPE, stderr=PIPE)
19
20 print("\n" + "{}.sig ".format(filename) + "signature file
        ↳ created for " + filename)

```

Bibliography

Paar, Christof and Pelzl, Jan. 2009. *Understanding Cryptography*. Springer. (In particular chapter 11 “Hash Functions”.)

Python. The Python Standard Library. “hashlib – Secure hashes and message digests”. <https://docs.python.org/3/library/hashlib.html>

Hellström, Henrick. 2015. “SHA-256 “almost unique”?”. <https://crypto.stackexchange.com/questions/29650/sha-256-almost-unique>

The GNU Privacy Handbook. <https://www.gnupg.org/gph/en/manual/book1.html>. In particular “Chapter 1. Getting Started”. <https://www.gnupg.org/gph/en/manual/c14.html>